

## CONDUCTIVE FILLER

This application claims the benefit of U.S. Provisional Application No. 60/112,957, filed December 18, 1998 and non-provisional Application serial number 09/458,489.

## BACKGROUND OF THE INVENTION

The present invention generally relates to a conductive filler and a method of making the filler. The filler is adapted for use in electrical coils, such as Roebel windings as a Roebel filler to fill interstices between the windings and a casing wall. The filler of the present invention is also useful in other applications where a flexible and/or compressible conductive material is needed. For example, the present filler can be used in the construction of an electrically shielded cabinet.

Various techniques for filling voids between parts in electrically conductive devices are known. Unfortunately, many prior art techniques do not succeed in completely filling the voids and/or suppressing electrical discharge across the voids. Many void fillers act as a dielectric and allow a voltage to be impressed across the filler. Failure to fill the voids or at least suppress discharge will result in undesirable arcing between the components. Arcing leads to diminished efficiency and diminished life expectancy of the device.

An example of a conductive device where voids are present is a high voltage coil having windings that are intertwined in a braid-like fashion to form a Roebel bar. Roebel bars, or Roebelled windings, have a highly discontinuous surface. This surface has a great number of voids, or interstices, which must be properly filled in order to reduce mechanical and electrical stresses. U.S. Patent No. 5,175,396 dated December

29, 1992 to Emery, incorporated herein by reference, discloses such a Roebel bar. The 5,175,396 patent discloses a prior art void filler made from Dacron felt impregnated with epoxy. The 5,175,396 patent is directed to providing a void filler made from an insulating layer of mica paper and B stage epoxy. A semiconductive layer, preferably a paste of carbon filled epoxy, is placed between the inner insulating layer and a groundwall.

Other filler materials have been used to fill voids in electrical coils. Discussion of a resin rich felt material may be found in U.S. Patent No. 5,633,477 dated May 27, 1997 to Smith. Discussion of an inert filler material and a pyrolyzed glass fiber layer electrically coupled to the strands of a coil may be found in U.S. Patent No. 5,066,881 to Elton. These fillers, and other prior art fillers and pre-pegs, are often difficult to install in high voltage coils and/or are not suitable for use in other applications, such as in the construction of an electrically shielded cabinet.

## SUMMARY OF THE INVENTION

The present invention overcomes these disadvantages by providing an electrically conductive filler, the filler having a substantially non-conductive core and a conductive layer. The conductive layer is wrapped around the core to form a closed loop thereby establishing conductivity from a bottom of the filler to a top of the filler by paths on each of two sides of the filler.

According to another aspect of the invention, the conductive layer is wrapped around the core such that the top of the filler is provided with two laminations of the conductive layer.

The present invention provides a method of making a web of conductive filler by

placing a web of core material onto an interior surface of a web of conductive layer material. The webs of core material and conductive layer material are directed through a forming station. The forming station turns first and second edges of the conductive layer material upward, folds the first edge of the conductive layer material over the core material, and folds the second edge of the conductive layer material over the first edge of conductive layer material.

#### BRIEF DESCRIPTION OF THE DRAWING

These and further features of the present invention will be apparent with reference to the following description and drawings, wherein:

FIG. 1A is an end view of a conductive filler according to a first embodiment of the present invention.

FIG. 1B is an end view of a conductive filler according to a second embodiment of the present invention.

FIG. 2 is a perspective view of the conductive filler, according to either embodiment, shown in an intermediate stage of assembly.

FIG. 3 is a perspective view of a Roebel winding having the conductive filler of the second embodiment.

FIG. 4 is a schematic of an assembly line for producing the conductive filler according to either embodiment of the present invention.

FIGS. 5A to 5F are schematic views showing various stages of production for the conductive filler according to the present invention.

FIG. 6 is a perspective view of a forming station according to the present invention.

## DESCRIPTION OF THE INVENTION

In the detailed description which follows, identical components have been given the same reference numerals, regardless of whether they are shown in different embodiments of the present invention. In order to clearly and concisely illustrate the present invention, the drawings may not necessarily be to scale and certain features may be shown in somewhat schematic form.

Referring to FIGS. 1A, 1B, 2 and 3, the present invention provides a conductive filler 10. The conductive filler 10 is adapted to fill voids in electrical devices. For example, the filler 10 can be used to fill voids, or interstices 12, created between transposed conductor windings 14 and a groundwall, or casing wall 16, of an electric coil 18 (FIG. 3). A coil 16 of this nature is commonly referred to as a Roebel bar. Additional discussion of Roebel bars is contained in U.S. Patent No. 5,175,396 dated December 29, 1992 to Emery, incorporated herein by reference. The filler 10 is preferably conductive to suppress electrical discharges. To fill as much of the voids as possible, the filler 10 is preferably compressible. Two lengths of filler 10 are preferably used in each bar, one length being disposed on top of the conductor windings 14 and the other disposed below. Alternatively, additional lengths can be provided along the sides of the winding stacks. In another alternative, lengths of filler 10 can be wrapped around the windings 14.

The filler 10 is preferably conductive, flexible and compressible. These qualities make the filler 10 effective to fill interstices 12 of different shapes and sizes. The conductive properties of the filler 10 prevents voltage from being impressed across an otherwise dielectric filler. If the filler 10 were not conductive, voltage would appear across the filler 10 and undesirable electrical discharges would occur. Accordingly, the

1 filler 10 is well suited for use in Roebel bars and in applications other than electric coils.  
2 For example, the filler can be placed between the panels of an electrically shielded  
3 cabinet.

4 The filler 10 provides a core 20. The core 20 is preferably non-conductive. The  
5 core 20 is preferably a felt-like, non-woven material, such as a polyester felt or aramid  
6 fiber batts, such as NOMEX. Preferably, the core 20 weighs about 9 ounces per square  
7 yard. Preferably, the core 20 is resin rich. More specifically, the core 20 is preferably  
8 impregnated with an epoxy, such as bis-a. The epoxy assists the filler 10 in conforming  
9 to and staying in the interstices 12 found in a Roebel bar. The core 20 is preferably  
10 50% to 90% loaded with epoxy, more preferably 65% to 85% loaded and most  
11 preferably about 80% loaded. A suitable core 20 material is available from Lectromat,  
12 Inc., P.O. Box 608, 18 Mars, Pennsylvania, 16046.

13 The filler 10 also provides a conductive fleece, or conductive layer 22, which is  
14 wrapped completely around the core 20 to form a closed loop around the core 20. The  
15 conductive layer 22 has an interior side 24 disposed towards the core 20 and an  
16 exterior side 26 disposed away from the core 20. The conductive layer 22 is preferably  
17 made from polyester fibers which are themselves not conductive. The fibers are  
18 preferably impregnated with a resin containing a conductive substance, such as carbon.  
19 The fibers of the conductive layer 22 are loaded with resin so that the conductive layer  
20 22 has a resistance of about 200  $\Omega$  per square. Depending on the application for the  
21 filler 10, the resistance per square can be widely varied such as 10 to 1,000,000  $\Omega$  per  
22 square. However, for use in an electric coil 18, a resistance of 200  $\Omega$  per square will  
23 provide sufficient conduction between the casing 16 and the windings 14 to suppress  
24 corona discharge. Suitable material for the conductive layer 22 is available from Isovolta

in Vienna, Austria under the name CONTAFEL-H 0865.

The conductive layer 22 is preferably wrapped completely around the core 20 as best illustrated in FIGS. 1A and 1B. Since the conductive layer 22 is wrapped completely around the core 20 to form a closed loop, conductivity is established from a bottom of the filler 10 to a top of the filler 10 by paths on both sides of the filler 10. A first embodiment of the filler 10 is illustrated in FIG. 1A. In the first embodiment, the conductive layer 22 is wrapped completely around the core 20 with a small portion of the conductive layer 22 overlapping itself.

A second embodiment of the filler 10 is illustrated in FIG. 2A. In the second embodiment, the conductive layer 22 is wrapped completely around the core 20 with a large portion of the conductive layer 22 overlapping itself. More specifically, the conductive layer 22 is layered on a top 28 of the core 20 such that a first edge 30 of the conductive layer 22 is generally aligned with a first edge 32 of the core 20. The conductive layer 22 wraps around a second edge 34 of the core 20, a bottom 36 of the core 20 and the first edge 32 of the core 20. The conductive layer 22 continues to wrap around the core 20 such that the conductive layer 22 is layered on top of itself. A second edge 38 of the conductive layer 22 is generally aligned with the second edge 34 of the core 20. As one skilled in the art will appreciate, the fillers 10 of the first and second embodiment are essentially the same, but the conductive layer 22 of the second embodiment is wider than the conductive layer 22 of the first embodiment such that the conductive layer 22 of the second embodiment overlaps itself more than that of the first embodiment.

To show additional features of both embodiments of the filler 10, FIG. 2 shows the core 20 placed on the interior side 24 of the conductive filler 22 in an intermediate

stage of assembly. The assembly process will be described in more detail below. To establish adhesion of the conductive layer 22 to the core 20, the filler 10 is preferably provided with a first layer of pressure sensitive adhesive 40 and a second layer of pressure sensitive adhesive 42. The first and second layers of adhesive 40, 42 are preferably strips of transfer adhesive made from an acrylic with a polyester carrier. The first and second adhesive layers 40, 42 are preferably about 0.25 millimeters thick.

As best illustrated in FIG. 2, the first strip of adhesive 40 is disposed on the interior side 24 of the conductive layer 22 adjacent a first edge 30 of the conductive layer 22. The second strip of adhesive 22 is disposed on the interior side 24 of the conductive layer 22 adjacent a second edge 38 of the conductive layer 22.

As illustrated in FIG. 1A for the first embodiment of the filler 10, when the conductive layer 22 is wrapped around the core 20, the first adhesive layer 40 preferably secures the area adjacent the first edge 30 of the interior surface 24 of the conductive layer 22 to the top 28 of the core 20. The second adhesive layer 42 preferably secures the area adjacent the second edge 38 of the interior surface 24 of the conductive layer 22 to the exterior surface 26 of conductive layer 22 adjacent the first edge 30, or to both the exterior surface 26 of the conductive layer 22 adjacent the first edge 30 and the top 28 of the core 20 as illustrated. In this way, the conductive layer 22 slightly overlaps itself and is, at a minimum, wrapped completely around the core 20. As one skilled in the art will appreciate, the conductive layer 22 may be secured to and wrapped around the core 20 in other ways. For instance, the conductive layer 22 may be wrapped only partially around the core 20.

It is advantageous to wrap the conductive layer 22 completely around the core 20 so that there is electrical conductivity between the top and the bottom of the filler 10.

1 It is desirable to provide this electrical conductivity along both sides of the filler 10  
2 because, in some situations, a corner of the filler 10 may be shaved to size the filler 10  
3 for use in a particular application. If the corner is shaved, or damaged, a disconnect in  
4 the electrical conductivity will result in the shaved area. However, the conductivity  
5 between the top and the bottom of the filler 10 will not fail since the other side of the  
6 filler 10 will remain electrically conductive.

7 As illustrated in FIG. 1B for the second embodiment of the filler 10, when the  
8 conductive layer 22 is wrapped around the core 20, the first adhesive layer 40  
9 preferably secures the area adjacent the first edge 30 of the interior surface 24 of the  
10 conductive layer 22 to the top 28 of the core 20 adjacent the first edge 32 of the core  
11 20. The second adhesive layer 42 preferably secures the area adjacent the second  
12 edge 38 of the interior surface 24 of the conductive layer 22 to the exterior surface 26  
13 of the conductive layer 22 adjacent the second edge 34 of the core 20.

14 The second embodiment of the conductive filler 10 is the preferred embodiment  
15 for use in a Roebel bar. This is because the resin from the core 20 can raise the  
16 resistance of the conductive layer 22. To keep the resistance at a desirable level it is  
17 preferable to have two laminations of the conductive layer 22 on at least one side of the  
18 filler 10. This side of the filler 10 is preferably placed toward the windings 14 of the  
19 Roebel bar as illustrated in FIG. 3. Alternatively, the filler 10 of the first embodiment can  
20 be used with or without other means of maintaining the conductive layer's resistance.  
21 Other potential solutions include modifying the filler 10 of the first embodiment. Example  
22 modifications include lowering the initial resistance of the conductive layer 22, modifying  
23 the thickness of the conductive layer 22, or reducing the amount of resin in the core 20.

24 To assist placement of the filler 10 in coils 18, cabinets and the like, the exterior



1 surface 26 of the conductive layer 22 is preferably provided with an outer adhesive layer  
2 44. The outer adhesive layer 44 is preferably the same type of adhesive as the first and  
3 second inner adhesive layers 40, 42, but is also provided with a release liner 46. The  
4 release liner 46 prevents the filler 10 from adhering to itself when the filler 10 is rolled  
5 for storage and packaging, and protects the underlying adhesive layer 44 until the  
6 release liner 46 is removed. The outer adhesive layer 44 can be provided on virtually  
7 any location on the outer surface 26 of the conductive layer 22. For most applications,  
8 the outer adhesive layer 44 need only provide enough adhesion to temporarily hold the  
9 filler 10 in place until the apparatus in which the filler 10 is being used is fully assembled  
10 and the filler 10 cannot be easily moved out of place under normal operating conditions.

11 For use in electrical coils 18 such as Roebel bars, the outer adhesive layer 44  
12 is preferably placed in the center of one side of the filler 10. In the second embodiment,  
13 the adhesive layer 44 is placed on the side of the filler 10 having the overlapping layers,  
14 or two laminations, of conductive layer 22 as illustrated in FIG. 1B. This allows the filler  
15 10 to be secured to the conductor windings with the overlapping layers 22 of conductive  
16 layer adjacent the conductor windings 14 as illustrated in FIG. 3.

17 Tests of the filler 10 according to the second embodiment of the present  
18 invention were conducted. The tests were conducted under IEEE Standard 286 (1975),  
19 titled "IEEE Recommended Practice for Measurement of Power-factor Tip-Up of  
20 Rotating Machinery Stator Coil Insulation," incorporated herein by reference. Under  
21 IEEE Std. 286, the power factor, and resultant Tip-Up value, of four 2,0kV production  
22 style Roebel bars as illustrated in FIG. 3 were measured. Two of the test bars contained  
23 filler 10 according to the second embodiment. The other two bars contained  
24 non-conductive fillers made from aramids, more specifically a resin rich B-stage aramid

and a polyester felt without resin. A low Tip-Up value represents an efficient coil. Preferably, the Tip-Up value is less than 1%. The coils containing the filler 10 according to the second embodiment had very desirable Tip-Up values of 0.48% and 0.51% respectively. The test results also indicate that there is a high repeatability in the performance of the bars using the filler 10. The bar containing a B-stage aramid filler has a Tip-Up value of 1.13%. The bar containing a resin free polyester felt has a Tip-Up of 2.570. The following chart shows the power factor, in percent, for each bar at various test voltages.

Test Voltage (kVrms)	Power Factor (Tan Delta (%))			
	Filler #1 (With Conductive Layer 10; Tip- Up of 0.51%)	Filler #2 (With Conductive Layer 10; Tip- Up of 0.48%)	Filler #3 (B-stage aramid; Tip- Up of 1.13%)	Filler #4 (Polyester Felt; Tip-Up of 2.57%)
3.3	0.96	0.94	1.20	1.16
6.6	1.24	1.23	1.38	1.68
9.9	1.40	1.33	1.80	2.75
13.2	1.47	1.42	2.33	3.75
16.5	1.57	1.56	2.97	4.51
19.6	1.67	1.66	3.46	5.10

FIGS. 4, 5A to 5F, and 6 illustrate a device and a preferred method of producing the conductive filler 10 of the present invention. As best shown in FIGS 4 and 5A, a first unwind station 60 is provided with a supply roll 62 of a web of conductive layer 22 of the conductive material 64 for forming the conductive layer 22 of the conductive fill 10. It is noted that throughout the method of producing the conductive filler 10 that tensioning

1 rollers are used as needed. Some of the rollers are illustrated but not discussed herein.

2 The web of conductive layer material 64 is directed to a second unwind station  
3 66 provided with a pair of supply rolls 68 of webs of adhesive. A first supply roll 68a of  
4 adhesive provides a web of adhesive layer material 70a for the first adhesive layer 40  
5 and a second supply roll 68b of adhesive provides a web of adhesive layer material 70b  
6 for the second adhesive layer 42. The webs of adhesive material 70a, 70b on the  
7 supply rolls 68a, 68b are each provided with a suitable release liner 72a, 72b. The webs  
8 of adhesive layer material 70a, 70b, along with their release liners 72a, 72b are  
9 unwound and respectively positioned on the interior surface 24 of the web of conductive  
10 layer material 64 along the first edge 30 and second edge 38 of the conductive layer  
11 22. The webs of conductive layer material 64, adhesive layer material 70a, 70b and  
12 release liners 72a, 72b pass through a pair of pressure or pinch rollers 74 which apply  
13 pressure to secure the web of conductive layer material 64 and webs of adhesive 70a,  
14 70b together. The release liners 72a, 72b are then removed from the webs of first and  
15 second adhesive layer material 70a, 70b by, a suitable liner collector 76. The liners 72a,  
16 72b can be advantageously removed and collected by a vacuum device. The filler 10  
17 at this stage of production is best illustrated in FIG. 5b and is made of the web of  
18 conductive layer material 64 provided with the webs of first and second adhesive layer  
19 material 70a, 70b respectively placed along the first edge 30 and second edge 38 of the  
20 conductive layer 22.

21 The web of conductive layer material 64 and the webs of adhesive layer material  
22 70a, 70b are directed to a third unwind station 78. The third unwind station 78 is  
23 provided with a supply roll 80 of a web of core material 82. The web of core material 82  
24 is unwound and positioned onto the interior surface of the web of conductor layer

1 material 64 between the first and second edges 30, 38 of the web of conductive-layer  
2 material 64 and between the webs of first and second adhesive layer material 70a, 70b  
3 as best illustrated in FIG. 5C.

4 The web of core material 82, webs of adhesive layer material 70a, 70b and the  
5 web of conductive layer material 64 are directed to a forming station 86. As best  
6 shown in FIGS. 4, 5D and 6, the forming station 86 folds the web of conductive layer  
7 material 64 around the web of core material 82 by upwardly bending, or folding, the first  
8 and second edges 30, 38 of the web of conductive layer material 64.

9 The forming station 86 further wraps the web of conductive layer material 64  
10 around the web of core material 82 so that the first edge, 30 of the web of conductive  
11 layer material 64 is wrapped onto the top surface 28 of the web of core material 82 and  
12 the second edge 38 of the web of conductive layer material 82 is wrapped onto the web  
13 of conductive layer material 82, as illustrated in FIG. 5E. Wrapped in this manner, the  
14 web of conductive layer material 64 is now wrapped completely around the web of core  
15 material 82. It is noted that the folds in the web of conductive layer material 64 are  
16 started by hand, but, once started, the rest of the web of conductive layer material 64  
17 is folded automatically. It is noted however that the entire folding, or cuffing, process  
18 can be automated using suitable tooling.

19 Referring to FIG. 6, the forming station 86 provides a die 88 defining a  
20 "U-shaped" channel, or passageway 90, a roller 92, a base 94 and a series of posts 96.  
21 The webs of conductive layer material 64, adhesive layer material 70a, 70b, and core  
22 layer material 82 pass through the U-shaped passageway 90. The portions of the web  
23 of conductive layer material 64 that are to be folded onto the top 28 of the web of core  
24 material 82 are bent upward and pass through respective leg portions of the

1 passageway 90. The web of core material 82 and the remaining portion of the web of  
2 conductive layer material 64 pass through a base of the passageway 90. To help  
3 prevent snagging and tearing of web the core material 82 and the web of conductive  
4 layer material 64, the die 88 can optionally be lined with a piece of low friction guide  
5 material 98 surrounding the passageway 90. After the webs 64, 70a, 70b, 82 pass  
6 through the passageway 90, the web of conductive layer material 64 has a U-shaped  
7 cross section matching the shape of the passageway 90 and the portion of the exterior  
8 surface 26 of the web of conductive layer material 64 that forms the bottom of the liner  
9 10 slides along the base 94. The web of core material 82 is weighted downward and  
10 held in position by the roller 92 by trapping the web of core material 82 and the web of  
11 conductive layer material 64 between the roller 92 and the base 94. The roller 92 is  
12 allowed to rotate about an axis on an axle 100 supported by stanchions 102. The  
13 circumference of the roller 92 may also be provided with a low friction material.  
14 Optionally, the circumference of the roller 92 may have a concave or convex profile to  
15 shape the web of core 10 material 82.

16 After the webs 64, 82 pass under the roller, the upwardly turned portions of the  
17 web of conductive layer material 64 are wrapped completely around the web of core  
18 material 82. This is accomplished by bending the first edge 30 of the web of conductive  
19 layer material 64 toward the first edge 32 of the web of core material 82 and  
20 subsequently bending the second edge 38 of the web of conductive layer material 64  
21 over the first edge 32 of the web of conductive layer material 64 and toward the second  
22 edge 34 of the web of core material 82. This wrapping process is carried out by the  
23 series of posts 96. Preferably, the posts 96 are securely mounted in the base 94. A first  
24 set of progressively bent posts 104 direct the first edge 30 of the web of conductive

1 layer material 64 over the web of core material 82 towards the first edge 32 of the web  
2 of core material 64 to form a first, or inner, conductor layer lamination 106 (FIG. 5E)  
3 disposed on the top 28 of the web of core material 82. A first set of guide posts 108 are  
4 disposed on the opposite side of the web of partially formed filler material from the first  
5 set of progressively bent posts 104 to help the web of partially formed filler material  
6 continue to travel in a linear fashion. A second set of progressively bent posts 110 are  
7 located on the opposite side of the partially formed filler from the first set of  
8 progressively bent posts 104 but down stream from the first set of guide posts 108. The  
9 second set of progressively bent posts 110 direct the second edge 38 of the web of  
10 conductive layer material 64 over the inner conductor layer lamination 106 to form a  
11 second, or outer, conductor layer lamination 112 (FIG. 5E) on the exterior surface 26  
12 of the inner conductor layer lamination 106. A second set of guide posts 114 are  
13 disposed on the opposite side of the web of partially formed filler material from the  
14 second set of progressively bent posts 110 to help the web of partially formed filler  
15 material continue to travel in a linear fashion. One skilled in the art will appreciate that  
16 the wrapping need not be carried out by posts or finger like projections as illustrated,  
17 but can be carried out by other types of barriers that are arranged to direct the  
18 conductive layer into position, such as by strips of sheet metal.

19 Referring to FIG. 4, the web of core material 82 and the now wrapped web of  
20 conductive layer material 64 are directed to a forth unwind station 120. The forth unwind  
21 station 120 is provided with a supply roll 122 of a web of adhesive and liner material  
22 124 for forming the outer adhesive layer 44 and the release liner 46. As best shown in  
23 FIGS. 4 and 5F, the web of adhesive and liner material 124 is directed onto the top  
24 external surface of the web of conductive layer material 64 where it is centrally

1 positioned. The assembled filler 10 is then directed to a pair of pressure or pinch rollers  
2 126. The pinch rollers 126 apply pressure to set the webs of adhesive material 70a, 70b  
3 and supply sufficient pressure to secure the web of adhesive and liner material 124 to  
4 the web of conductive layer material 64, thereby forming a completed web 128 of  
5 conductive filler 10. The completed web 128 of the conductive filler 10 is then directed  
6 to a rewind station 130 where it is wound into a roll 132, preferably around a cardboard  
7 or plastic sleeve. Once rolled, the conductive filler 10 can be packaged and shipped.  
8 The rolled filler stock can be unwound and used in the production of electric coils,  
9 shielded cabinets and the like.

10 The rewind station 130 is provided with a first take up roller 134 and a second  
11 take up roller 136. Each take up roller 134, 136 is preferably provided with a clutch.  
12 Once a predetermined length of completed web 128 is wound on the first take up roller  
13 134, e.g., 225 inches, the clutch stops rotation of the roller 134. The completed web 128  
14 may then be cut and positioned for winding on the second take up roller 136. Rotational  
15 movement of the second take up roller 136 is stopped by its clutch after a  
16 predetermined length of completed web 128 is wound thereon. The completed web 128  
17 is then cut and moved to the first take up roller 134 and the foregoing process is 5  
18 repeated.

19 Although particular embodiments of the invention have been described in detail,  
20 it will be understood that the invention is not limited correspondingly in scope, but  
21 includes all changes and modifications coming within the spirit and terms of the claims  
22 appended hereto.